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COMPLETE STUDY OF THE MULTIPACTOR PHENOMENON FOR THE MYRRHA 80 kW CW RF COUPLERS*

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Abstract

MYRRHA (Multi Purpose Hybrid Reactor for High Tech Applications) is an Accelerator Driven System (ADS) project. Its superconducting linac will provide a 600 MeV - 4 mA proton beam. The first project phase based on a 100 MeV linac is launched. The Radio-Frequency (RF) couplers have been designed to handle 80 kW CW (Continuous Wave) at 352.2 MHz. This paper describes the multipacting studies on couplers.

INTRODUCTION

Multipacting is an undesired phenomenon of resonant electron build up encountered in electromagnetic field regions under vacuum. It appears when an electron is accelerated by the electric field and hits the enclosure's wall. Depending on the secondary electron yield of the wall, more than one electron can be emitted and accelerated by the electric field, creating a self-sustained electron avalanche. The coupler aims to transfer energy from the RF source to the accelerating cavities of the linac. It also provides a vacuum and a thermal barrier between air and the superconducting cavity while preserving its cleanliness.

As part of an ADS ('Accelerator Driven System'), the MYRRHA (Multi Purpose Hybrid Reactor for High Tech Applications) [1] coupler is laid out for the highest achievable reliability. To improve the reliability, the coupler is studied and tested up to 80 kW CW, well above its nominal power (8 kW CW), to allow the fault-tolerance schema [2]. The study includes a complete calculation of the multipactor phenomenon. MUSICC3D [3] and SPARK 3D codes have been chosen for the simulations.

COUPLER DESIGN OVERVIEW

The power coupler [4] is made (Fig. 1) of an inner conductor (antenna) and an outer conductor (cuff) brazed on a high purity alumina ceramic window. The antenna has a radius 13.1 mm (Rant) and the outer conductor, fixed by the cavity, is 28 mm. The coupler allows some mechanical flexibility to compensate differential thermal expansions and mechanical misalignments thanks to bellows. The antenna having a water cooling, a double input tee has been designed. This tee has a flange on one side to transport the RF power, and on the other side, a special short stub, to support cooling pipes all the way up through the antenna. The length of this short stub (Lss) was studied to eliminate the mismatch created by the bellows, which was a length of 270 mm.

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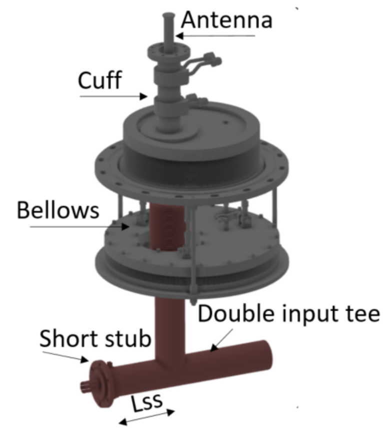

Figure 1: Main elements of the power coupler.

MUSICC3D CALCULATIONS

MUSICC3D (@IJC Lab/ IN2P3/France) uses a model of one virtual particle, where the output 'charge number' represents the product of SEYs (Secondary Electrons Yields) occurring at each interaction with the wall. It is considered that there is a multipacting barrier at a given field level, if the charge number increases at this field gradient.

The particle emission is based in the secondary emission Yield in function of the impact energy (SEY curves)

First simulations were made with MUSICC3D around the window because it is the most fragile and important region to prevent of multipactor. If window breaks the accelerator is no longer under vacuum.

The worst case was simulated, with no TiN anti-multipactor coating on the Al2O3. The Secondary Electron Yield (SEY) curves used are shown in Fig. 2.

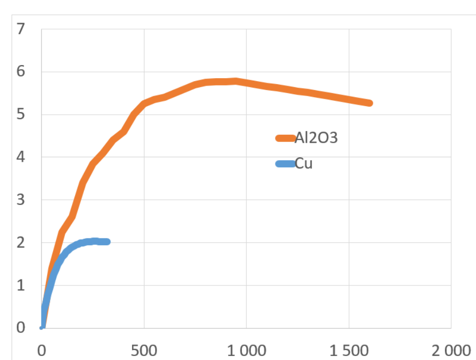

Figure 2: Al2O3 SEY curve (in red) and cu SEY curve (in blue).

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The first important multipacting barrier found was at 67 kW @ 0.37MV/m as can be identified on the Fig. 3 showing the charge number versus the peak electric field.

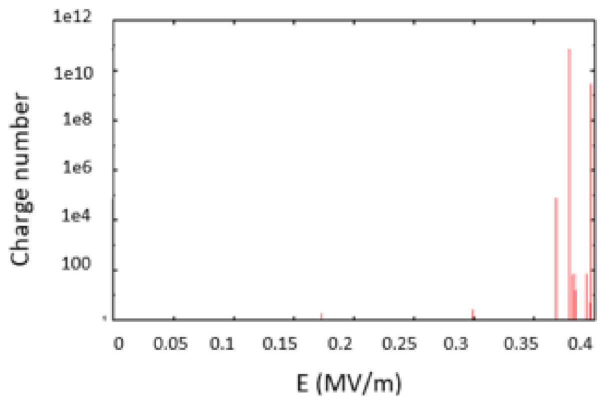

Figure 3: Charge number versus the peak electric field (MV/m) at 100 impacts.

This multipacting barrier has no resonant electron trajectories impacting the alumina disk of the coupler (See Fig. 4). So theoretically, there is no risk to break the alumina.

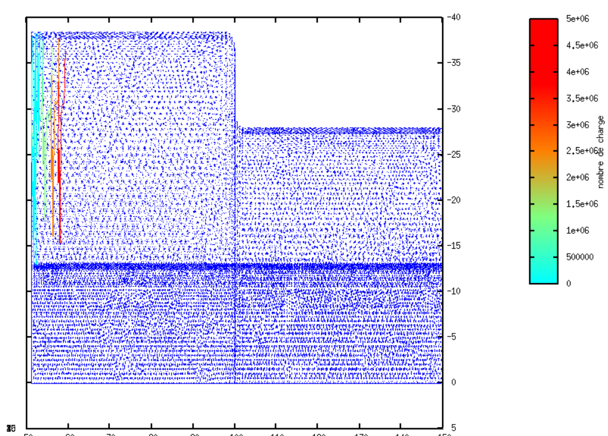

Figure 4: Electrons trajectories with MUSICC3D.

SPARK 3D CALCULATIONS

SPARK3D (@Dassault Systems) is part of a commercial electromagnetics (EM) package. The main output of SPARK3D is the curve of the electron evolution analysed in time for each RF power. For a given field level, if the electron evolution increases, multipacting occurs. The higher the electron evolution, the stronger the multipactor is. If the electron evolution for one frequency reached 10^{15} SPARK3D stops the simulation for that frequency. Simulations were made with 5000 electrons (4 e^{-}/cm^{2}) emitted in a homogeneous initial electron distribution. The SEY used was the same that for MUSICC3D simulation in the Vaughan model.

The goals of the SPARK3D simulation were to confirm the MUSICC3D calculations and to study the influence of some parameters such as the TiN coating, the length of the short stub and the inner radius of the antenna.

At the nominal conditions (Rant of 13.1 mm, Lss of 270 mm, with TiN), simulations show that from 10 to 55 kW multipactor appears at the cuff and from 55 kW multipactor is located around the window as predicted by MUSICC3D simulations in this region. The two stronger multipactors are those at the cuff: the first one at around 30 kW and the second one at around 45 kW (see Fig. 5).

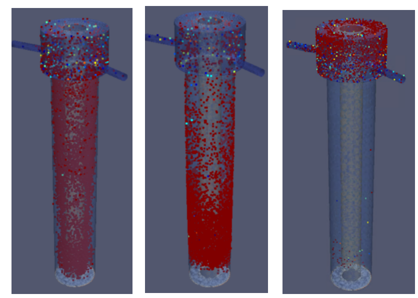

Figure 5: Multipacting zones, in red, at 30 kW (on the left); 45 kW (in the middle) and 55 kW (on the right).

Study of Electrons with vs Without TiN Coating

Simulations showed, as expected, that the TiN coating makes the multipactor around the window weaker. The SEY maximal used for the TiN was 1.75 versus 5,78 used for the Al2O3. The positive effect of the TiN is evident; it can reduce multipactor up to a factor of 10^5 (see Fig. 6) in the power range above 55 kW. In Fig. 6 the slope of the electron evolution, called electron growth rate, is given for each electrical field.

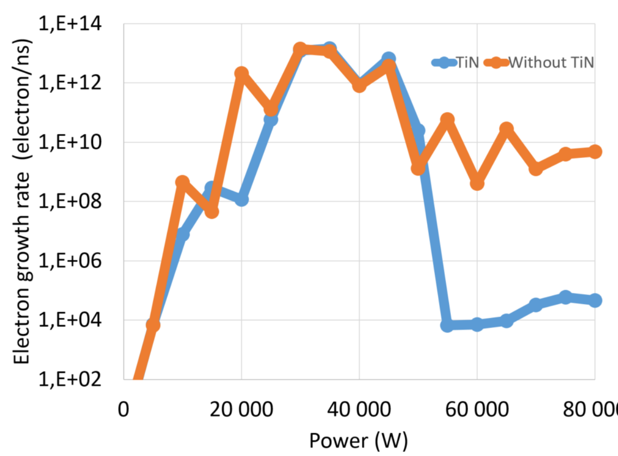

Figure 6: Electron growth rate with TiN vs without TiN. Rant 131 mm & Lss 270 mm.

Study of a Variation of the Short Stub's Length

For the best power transmission to the beam with a more constant EM field along the cuff the optimal short stub's length is 270 mm. Without bellows in the transmission line, the optimal length should be 230mm.

The numerical results show that for Lss of 270 mm, the two strongest multipacting barriers are narrower than Lss of 230 mm (see Fig. 7).

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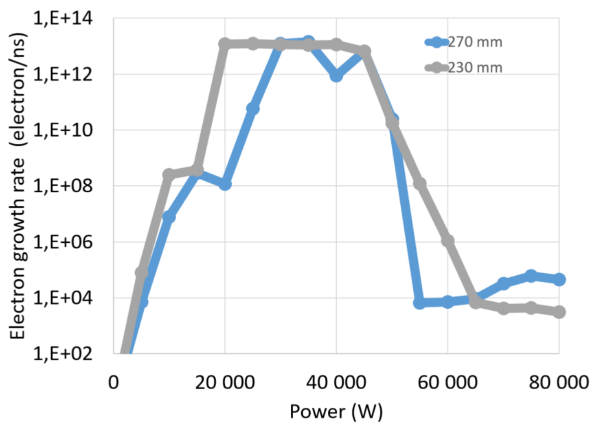

Figure 7: Electron growth rate with Lss 270 mm vs Lss 230 mm. Rant 13.1mm &TiN.

Influence of a Variation of the Antenna's Radius

The characteristic impedance (Zc) of a coaxial line depends on outer conductor radius (Rext) and on the antenna radius (Rant) as shown in the Eq [1].

$$Zc = \frac{1}{2\pi}\sqrt{\frac{\mu}{\varepsilon}}\, Ln\left(\frac{R_{ext}}{R_{ant}}\right) \quad (1)$$

In a coaxial line, Somersalo's laws [5] show that the multipacting power levels depends on the characteristic impedance, the frequency and the outer diameter (See Eq [2] for multipacting 1-point order 1 where $P_{1\text{-point}}$: Multipacting power level; f: Frequency; D: outer conductor diameter; Z_c :characteristic impedance).

$$P_{1-point} \propto (f\ D)^4\ Zc \quad (2)$$

In our case, the characteristic impedance is the only free parameter as the frequency and outer diameter are fixed. For that, two antenna radius have been studied; 13.1 mm @ 45.6 Ohm and 12.16 mm @ 50 Ohm.

Simulation results show that multipacting barriers for 13.1 mm are shifted at lower powers than for 12.16 mm (See Fig. 8). This result is consistent with Somersalo law.

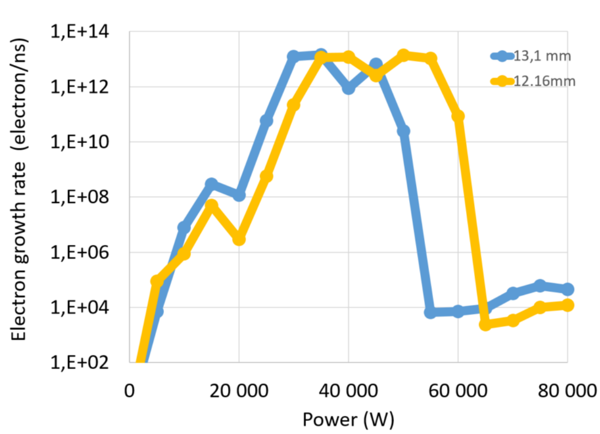

Figure 8: Electron growth rate for Rint 13.1mm vs 12.16mm. Lss 270 mm & TiN.

Study of the Coupling

Coupler coupling with the cavity conditioning and the spoke accelerating cavity was simulated. No multipactor in the coupling zone was observed.

CONCLUSIONS

MUSICC3D and SPARK 3D simulations provide approximately the same results. The prototype design with Lss of 270 mm and Rant of 13.1 mm show lower multipacting so these parameters have been validated. For this configuration (Lss@270 mm, Rant@13.1mm) the two stronger multipactors appear at the cuff around 30 kW and 45 kW. These multipacting barriers correspond with those measured and conditioned with the prototypes at the coupler test bench.

Multipacting barriers around the window were not easy to measure because there are weaker than at 30 and 45 kW. The next step is to choose whether or not to have the TiN coating on the window. The pros are that in MYRRHA the reliability is very important and TiN coating reduces very much the multipacting (more than a factor 100) around the window, confirmed by simulation. The cons are that TiN coating is not easy to realise and it has to be very well controlled; besides, multipacting barriers appear higher than 4 times the nominal power (8 kW).

No significant difference between the prototypes with/without TiN was measured during their conditioning.

New results are expected with the RF power test of the cryomodule prototype planned before the end of 2022.

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